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TITLE: Curved array of sequenced ultrasound transducers.

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ABSTRACT:

CHG DATE=19990617 STATUS=O> An array of ultrasound transducers for pulsed sector-scan operation includes a plurality of transducer elements disposed on an arc of a circle and oriented to emit and receive ultrasound radiation in the direction of the center of the arc. A group of adjacent transducers within the array is active for each ultrasound pulse. The position of the group in the array is incrementally shifted along the arc, one transducer

at a time, to
effect scanning. The inherent focussing affect of a curved group of
transducers is compensated with time delays or a negative lens to provide a
parallel, sector-scanned radiation beam. The array may be manufactured by
cutting grooves (620) in a solid bar of piezoelectric ceramic (600), casting
flexible matching windows (615) on the front surface of the grooved bar,
bending the grooved bar around a mandrel (650) to separate individual
transducer elements (630) from each other and casting a foam air cell (660)
over the back of the elements to retain them in place.

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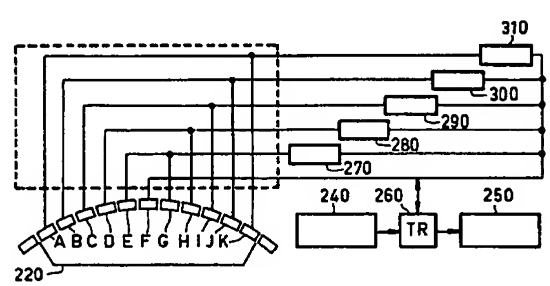
(54) **Curved array of sequenced ultrasound transducers.**

(57) An array of ultrasound transducers for pulsed sector-scan operation includes a plurality of transducer elements disposed on an arc of a circle and oriented to emit and receive ultrasound radiation in the direction of the center of the arc. A group of adjacent transducers within the array is active for each ultrasound pulse. The position of the group in the array is incrementally shifted along the arc, one transducer at a time, to effect scanning. The inherent focussing effect of a curved group of transducers is compensated with time delays or a negative lens to provide a parallel, sector-scanned radiation beam.

The array may be manufactured by cutting grooves (620) in a solid bar of piezoelectric ceramic (600), casting flexible matching windows (615) on the front surface of the grooved bar, bending the grooved bar around a mandrel (650) to separate individual transducer elements (630) from each other and casting a foam air cell (660) over the back of the elements to retain them in place.



ACTORUM AG

"Curved array of sequenced ultrasound transducers".

The invention relates to an array of ultrasound transducers which is particularly useful for medical imaging applications. More specifically, the invention relates to a curved, linear array of ultrasound transducer elements. A group of active elements are incrementally shifted along the array to sector-scan a parallel ultrasound beam.

BACKGROUND OF THE INVENTION

Internal body organs may be imaged and otherwise characterized by apparatus which directs pulses of ultrasound energy into the body and subsequently detects echoes which originate when the energy is reflected from tissue interfaces or other discontinuities within the body. In typical apparatus the ultrasound energy is directed into the body in a relatively narrow beam. Electric signals which describe the position and direction of the beam with respect to the body, as well as the relative arrival time and amplitude of the echos, are utilized to generate a visual display and/or mapping of the internal body structures. In many applications the direction of the ultrasound beam is manually controlled by a technician (generally by physical motion of a probe head) to build up a display pattern. While these methods are adequate for imaging stationary body structures, the time required for physical motion of a probe is generally much too long to image rapidly moving body structures (for example the valves in a heating heart) in real time. Ultrasound systems for generating real time displays of rapidly moving body organs generally utilize electromechanical or electronic means to change the position and direction of one or more beams of ultrasound energy with respect to the body.

Motion of a beam of ultrasound energy with respect to the body may be provided by sequentially activating

transducer elements in a flat linear array to effectively scan an area of the body with a sequence of substantially parallel ultrasound beams. A device of this type is described in U.S. Patent 3,013,170. A beam of ultrasound energy may, alternately, be scanned around a single origin point to produce a so-called "sector-scan". Sector-scan geometries are particularly useful since ultrasound energy may be directed between the ribs to scan the interior of the chest cavity. Sector-scanning has been achieved in the prior art by rapidly rotating one or more transducers about an axis, by steering energy from a fixed transducer with a rotating ultrasound reflector, or by sequencing individual transducer elements in a linear curved array. British patent 1,546,445 describes a curved transducer array with individual transducers which are individually activated to produce a sector-scan.

The transverse spatial resolution which may be obtained from a sequence array of ultrasound transducers is related to dimensions of the individual transducer elements in the array. Small transducer elements are desirable for obtaining fine resolution. The amount of ultrasound energy produced by an individual transducer element is, however, limited by its size. The signal-to-noise ratio of the returned ultrasound echoes necessarily depends on the amount of ultrasound energy introduced into the body. Thus, the signal to noise ratio suffers if small transducer elements are individually activated to achieve a scanning action. Diffraction effects will furthermore, cause spreading of an ultrasound beam which originates from a single, small ultrasound transducer element.

This problem has been solved in the prior art by simultaneously activating a group of adjacent transducers within a flat linear array. Means were provided for incrementally shifting the active group along the array to provide fine spatial resolution and high signal-to-noise ratios. While this technique is appropriate for use with flat transducer arrays, which produce a parallel beam scanning geometry, the simultaneous activation of a group

of adjacent transducers in a curved array inherently generates a focussed ultrasound beam. Sequenced group arrays have not, therefore, found application for the generation of high resolution sector-scans.

SUMMARY OF THE INVENTION

A concave linear array of small transducer elements is utilized to generate an ultrasound sector scan. A group of active elements is incrementally shifted along the array to provide a steerable beam providing high resolution and a high signal to noise ratio. Defocussing means, which compensate for the inherent focussing effects in a curved group of adjacent transducers, are provided. The defocussing means may comprise a negative ultrasound lens disposed between the array and the body. Alternately, the defocussing means may delay electrical signals, which are transmitted to and received from each transducer element in the active group, in proportion to the distance between that element and the center of the active group.

A curved array of small, high resolution transducer elements may be manufactured by first sawing the back surface of an electroded bar of piezoelectric ceramic to form a series of parallel grooves. A flexible matching window is cast on the front surface of the grooved bar. The bar and window are then bent around a convex mandrel so that the indivual elements are fractured one from the other. A foam air cell is then cast over the back of the elements to retain them in place.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention may be understood with reference to the attached drawings in which:

Figures 1 and 2 show a prior art sequenced flat array of ultrasound transducers;

Figure 3 is a curved transducer array of the present invention;

Figure 4 illustrates the principle of time delay defocussing for the array of Fig. 3;

Figure 5 schematically illutrates a system for

operating the array of Figure 3;

Figure 6 is an alternate embodiment of the invention which includes a defocussing lens;

Figure 7 illustrates a stage in the production of the array of Figure 3;

Figure 8 illustrates a completed array; and

Figure 9 is a detail of Figure 8.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Figure 1 is a linear array of ultrasound transducers 110 which is known in the prior art. A series of individual transducers elements 100 are disposed along a line 101. Separate electrodes 102 are provided for each transducer in the array and are connected to electronic circuits (not shown) which permit sequential activation of the elements to, in effect, move the source of an ultrasound beam along the line 101.

Figure 2 illustrates an application of the array 110 of Figure 1. A group of adjacent transducers 111 are simultaneously activated to produce a beam of ultrasound energy 112 which is inwardly projected into a body 113. The array 110 is disposed on the surface of a probe assembly 114 which includes switching circuits 115. The switching circuits act to incrementally shift the group of active transducers 111 along the array to generate a linear scan of the beam 112 with respect to the body. The operation of prior art imaging systems with incrementally shifted arrays is described in the articles Ultrasonic Imaging Using Arrays, Albert Macovski and Methods and Terminology for Diagnostic Ultrasound Imaging Systems, Maxwell G. Maginness in the Proceedings of the IEEE, Vol. 67, No. 4, April 1979 at page 484 and 641 respectively. Those articles are incorporated herein, by reference, as background material. As indicated in those articles, the incremental shifting of a group of transducers within the array improves spatial resolution and provides a higher signal to noise ratio than could be achieved by the sequential activation of individual transducer elements.

British patent Specification 1,546,445 describes a

curved linear array of transducers which are individually activated to generate a sector-scanned ultrasound beam. A positive (converging) lens is utilized with the transducer array to focus the beam through the spaces between the ribs. Because only one transducer element is active at a time, the array of British patent 1,546,445 suffers from relatively low spatial resolution and signal-to-noise ratio. The performance of the array cannot, however, be improved by directly applying the incrementally shifted active group geometry of Figure 2 to the curved array configuration. The simultaneous activation of a group of adjacent elements on a curved array necessarily produces a sharply focussed beam which diverges in the far field and is unsuitable for medical imaging.

Figure 3 schematically illustrates a transducer array of the present invention. A plurality of electro-acoustic transducer elements 200 are disposed along an arc and are oriented to project and receive ultrasound energy in the direction of the center of the arc. The individual elements 200 in the array are provided with separate electrodes and are connected, via wires 202, and a sequencing circuit to pulse generator and receiver circuits (not shown). The array is contained in a housing 204 which includes an ultrasound transmissive window 206. The housing may be filled with an ultrasound transmissive fluid 208, for example, castor oil, which is matched to the ultrasound transmissive properties of the human body. Alternately the housing may be filled with a solid material. In general the filling should have an acoustic attenuation between those of water and human tissue and should have an acoustic impedance which is matched to the impedance of human tissue.

A group of adjacent transducer elements (for example 220) within the array is activated for the transmission and reception of each ultrasound pulse. The active group of transducers is incrementally shifted along the array, one transducer at a time, on a pulse to pulse basis to provide a sector scan of ultrasound energy. Defocussing

means are included to compensate for the strong inherent focussing of the curved array. The curved array, with an incrementally shifted group of active detectors, in combination with the defocussing means, produces a finer spatial resolution and higher signal to noise ratio than curved sequenced arrays of the prior art.

Figure 4 illustrates a preferred embodiment of the defocussing means. At a given instant, a group 220 of adjacent transducers A-K within the array is activated by sequencing switches (not shown for the sake for clarity). The central transducer F within the zone is connected directly to ultrasound pulse generator 240 and receiver 250 circuits via a transmit-receive (TR) switch 260. The transducer pair E and G immediately adjacent the central transducer is connected to the TR switch 260 via a first delay 270. The next adjacent pair of transducers D and H are connected to the TR switch through a second delay circuit 280 which provides a longer delay than the delay circuit 270. Each next adjacent pair of transducers within the group (i.e. C and I, B and J, A and K) are connected to the TR switch via delay circuits (290, 300, 310) which provide increasing delays in proportion to the distance from the center of the active group to the associated transducers. The magnitude of the delays are chosen, using techniques which are well known in the art and which are described, for example, in the above referenced Macovski article, to compensate for the physical focussing effects of the curved array and thus provide a more parallel beam of ultrasound energy. Alternately the beam may thus be focussed at a point deep within the body of a patient.

Figure 5 illustrates a system for incrementally shifting the active group along the transducer array. Pulsers 400, receiver amplifiers 410, and associated TR isolators 420 are connected in a conventional fashion to first ends of a bank of bidirectional delay lines 430. The bank of delay lines 430 includes delay lines of varying time delay which are calculated to provide the defocussing compensation for the active group as described above with

respect to the Figure 4. The opposite end of each delay line in the bank 430 is connected to a row of switches in an analog switch matrix 440.Each column of switches in the switch matrix 440 is connected to a separate element 200 in the transducer array 450. A separate switch (which may be a MOS transistor) is provided at each cross point (that is the intersection of each row with each column) in the switch matrix. The switching elements are individually activated by the output lines of a read-only memory (ROM) 460. Input lines of the read-only memory 460 are addressed by the output of a sequencer circuit which may be a sequential counter 470 driven by a clock 480. The sequencer circuit addresses consecutive words in the read-only memory which establish the connection patterns between the individual transducer elements in the array and corresponding delay lines to effect incremental shifting of a defocussed, active group along the array. As an example, Table I illustrates the first three words of a read-only memory which shifts an active group of nine transducer elements along an array by establishing connections to four delay lines I through IV.

TABLE I

Delay Line	1	2	3	4	5	6	7	8	9	10	11	12	13	
I	0	0	0	1	0	0	0	0	0	0	0	0	0	
II	0	0	1	0	1	0	0	0	0	0	0	0	0	WORD 1
III	0	1	0	0	0	1	0	0	0	0	0	0	0	
IV	1	0	0	0	0	0	1	0	0	0	0	0	0	
I	0	0	0	0	1	0	0	0	0	0	0	0	0	
II	0	0	0	1	0	1	0	0	0	0	0	0	0	WORD 2
III	0	0	1	0	0	0	1	0	0	0	0	0	0	
IV	0	1	0	0	0	0	0	1	0	0	0	0	0	
I	0	0	0	0	0	1	0	0	0	0	0	0	0	
II	0	0	0	0	1	0	1	0	0	0	0	0	0	WORD 3
III	0	0	0	1	0	0	0	1	0	0	0	0	0	
IV	0	0	1	0	0	0	0	0	1	0	0	0	0	

The bit patterns of Table I are shortened for the sake of clarity of illustration; the principles illustrated therein may be extended to active groups and arrays which include larger or smaller numbers of transducer elements.

Figure 6 is an alternate embodiment of a transducer array wherein the defocussing means comprise a negative lens 500. A group of transducers is sequentially shifted across the array as in the embodiment of Figure 3 to produce a sector scan. All of the transducers in the group 200 may be simultaneously pulsed. Alternately, the delay line defocussing means of Figure 4 may be utilized in conjunction with the lens 500. The lens may be constructed from metal or plastic and may advantageously comprise two negative lens elements separated by a fluid-filled cavity 510.

Figure 7 illustrates first steps in a preferred method for manufacturing the transducer array. The array is advantageously formed from a single rectangular bar 600 of piezoelectric ceramic (which may comprise Type PZT-5). Copper electrodes 605 and 610 are bonded to the front 601 and rear 602 major surfaces of the bar with a silver bearing epoxy resin. A flexible matching window 615 is then cast directly on the front electrode. The matching window may be advantageously cast from a mixture of two parts of a Stycast 1264 resin binder and one part tungsten powder. The window is cast by pouring the mixture directly onto the surface of the front electrode and allowing the tungsten powder to settle. After the resin is cured, the window is machined to a thickness of one quarter acoustic wavelength at the operating frequency of the array. For example, a window designed for operation at 3.5 MHz is machined to approximately 0.09 mm thickness.

A series of parallel grooves 620 are then cut through the rear electrode 610 and into the upper surface of the bar to segregate individual transducer elements 630 with their associated rear electrodes. Typically the grooves are approximately 0.13 mm wide and penetrate to 75% of the thickness of the ceramic bar.

In a preferred embodiment of the array the ceramic bar is approximately 80.5 millimeters long, 12.5 millimeters wide, and 2.0 millimeters thick. The bar is divided by 71 saw cuts to form 72 transducer elements. The rear electrodes on the endmost transducer elements are grounded to the front electrode so that the array comprises 70 functional transducer elements.

Figures 8 and 9 illustrate the further construction of the array. The grooved ceramic bar 600 with attached electrodes 605 and 610 and window 615 is formed around a semicylindrical mandrel 650, the grooves in the bar being parallel to the axis of the cylinder. As illustrated in detail Figure 9 the bar cracks under each groove 620 to produce a curved array of separate, electroded transducer elements 630 which are retained in place by the front electrode 605 and window 615.

A supporting foam air cell 660 is then cast between the elements 630 and around the rear surface of the curved transducer array. The air cell retains the transducer elements in place and further provides a low acoustic impedance backing for the individual elements. The air cell may typically comprise glass micro-balloons in an epoxy resin binder.

In a preferred embodiment of the invention the upper electrodes 610 are wider than the ceramic bar and are folded back along the edges of the air cell to provide electrical connections to the individual elements.

CLAIMS:

1. A method for manufacturing a curved array of ultrasound transducer elements comprising the steps of:

attaching front and rear conductive electrodes to front and rear surfaces respectively of a bar of piezoelectric ceramic;

cutting a plurality of parallel grooves through the rear electrode and partially through the thickness of the bar;

placing the front surface of the grooved bar on a semicylindrical mandrel, the grooves being parallel to the axis of the mandrel, and bending the bar around the mandrel; fracturing portions of the bar under the grooves to separate individual transducer elements, the individual elements being retained against the mandrel by at least the front electrode; and

filling the spaces between the individual transducer elements with a resin binder which retains the elements on an arc conforming to the surface of the mandrel.

2. The method of claim 1 further comprising the step of attaching a matching window to the front electrode.

3. The method of claim 2 wherein the matching window comprises tungsten powder in a resin binder.

4. The method of claim 1 wherein the resin binder between the elements includes glass micro-balloons.

5. The method of claim 2 wherein the matching window is cast directly on the front electrode.

6. The method of claim 5 wherein:

the window is cast from a mixture of a liquid resin and metal powder; and further comprising the step of

allowing the powder to settle on the surface of the front electrode prior to solidification of the liquid resin.

7. The method of claim 6 wherein the metal is tungsten.

8. The method of any of claims 1-7 further comprising the step of machining the thickness of the window to approximately one quarter acoustic wavelength at the operating frequency of the array.

9. The method of any of Claims 1-7 wherein the window is flexible and is attached to the electrode prior to the bending step.

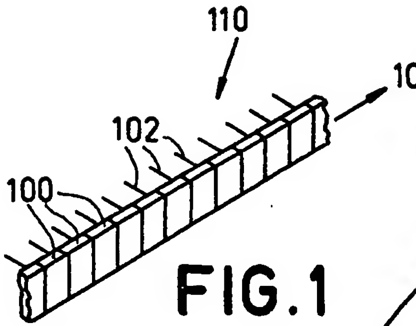


FIG.1

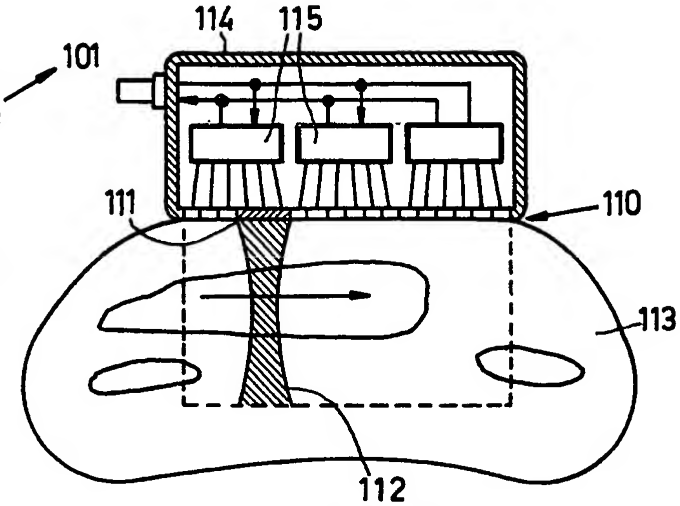


FIG.2

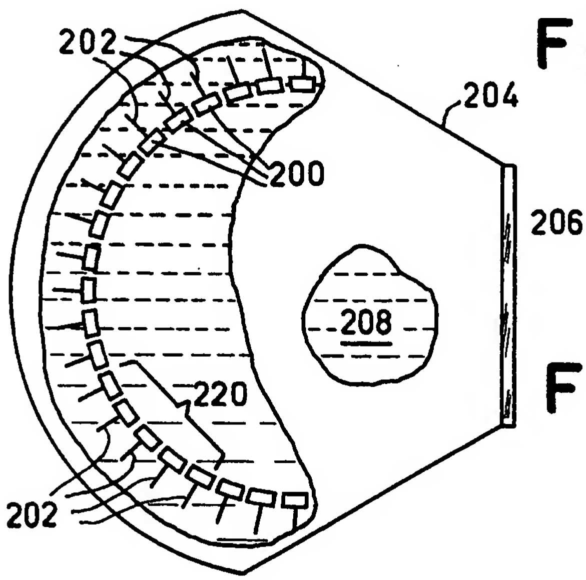


FIG.3

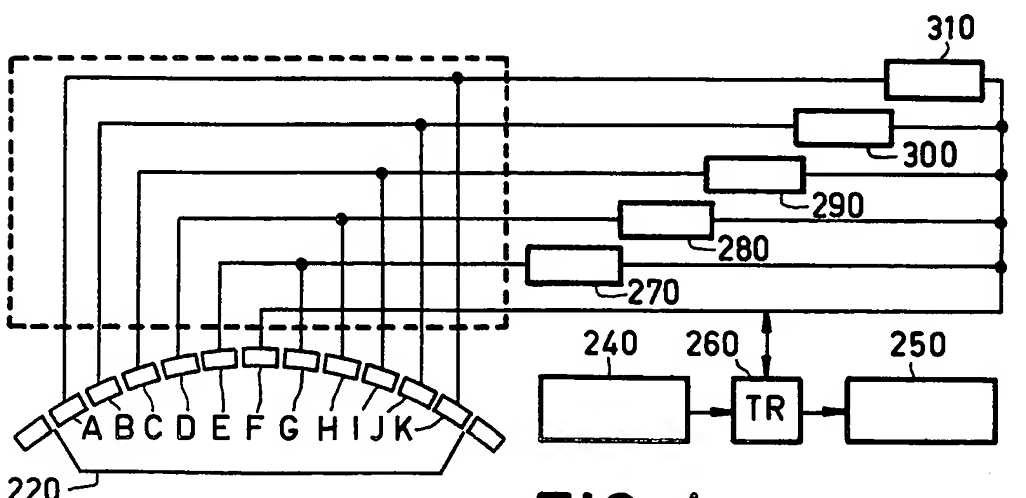


FIG. 4

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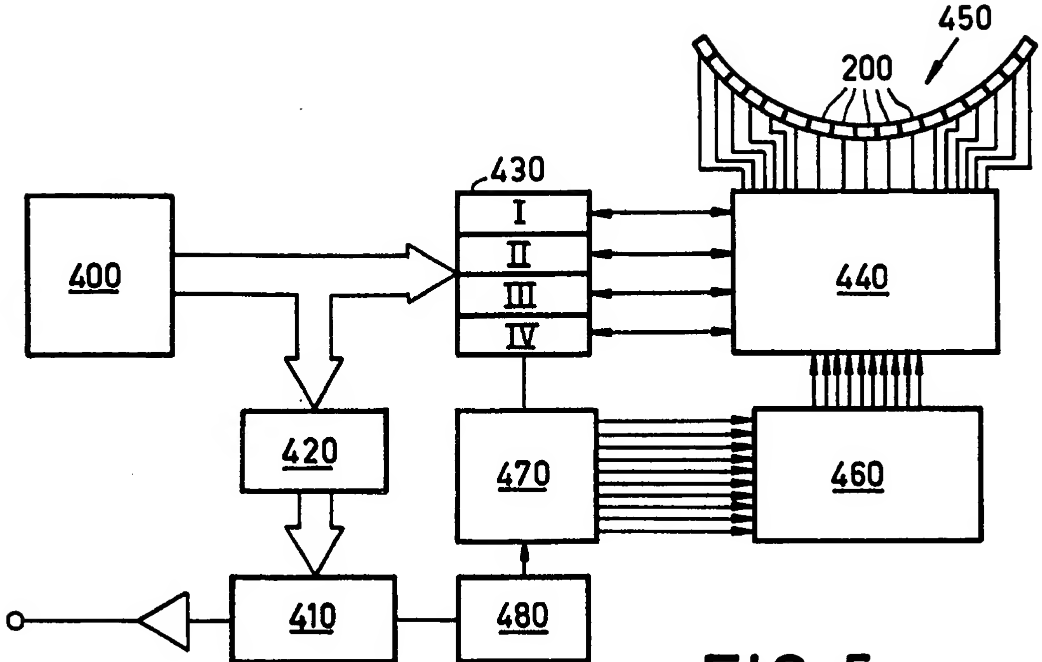

FIG. 5

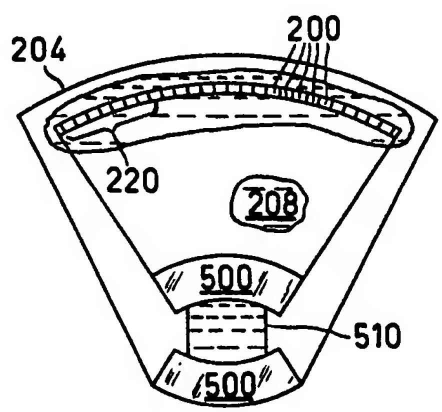

FIG. 6

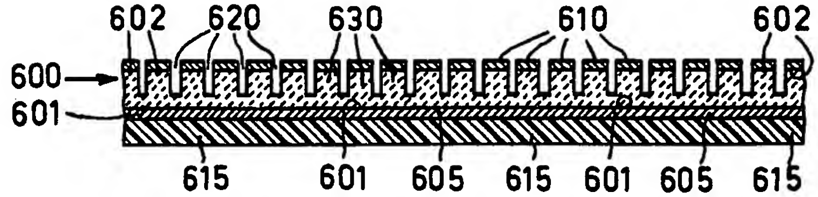

FIG. 7

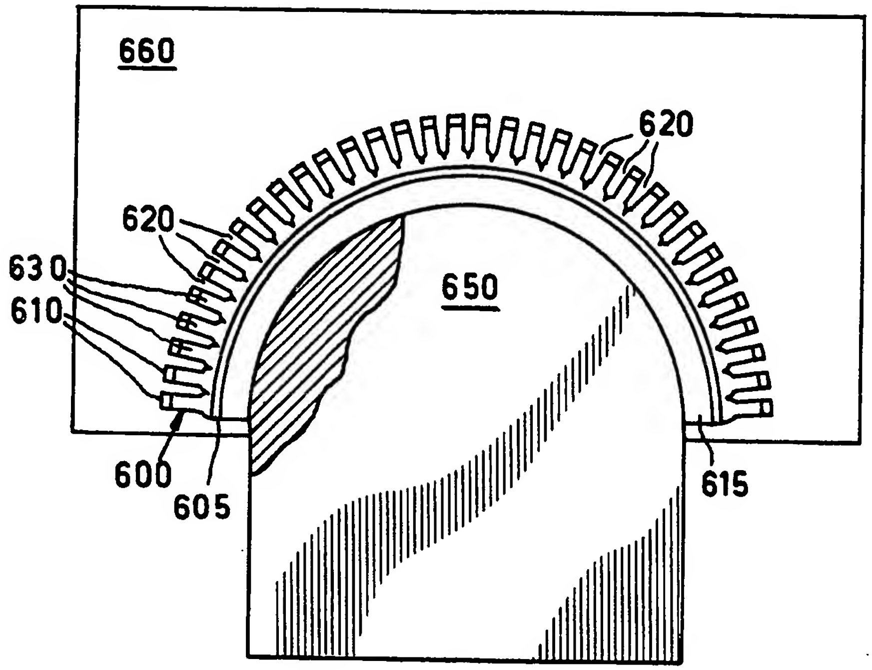

FIG. 8

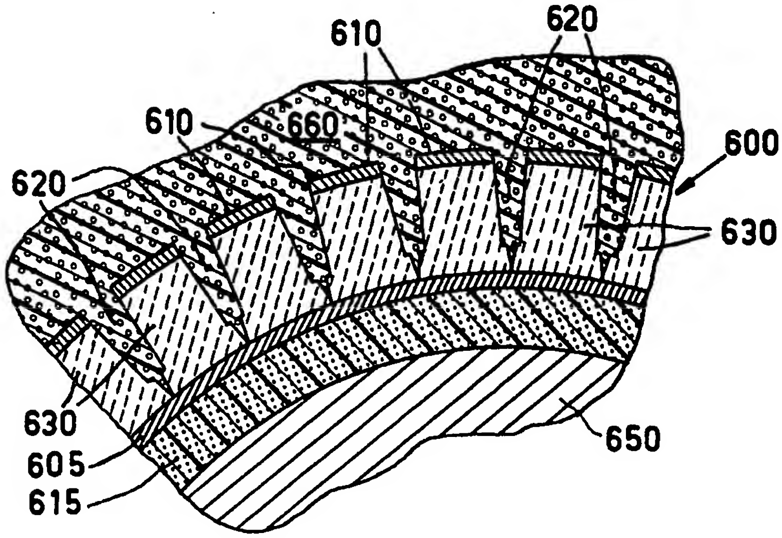

FIG.9

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European Patent Office

EUROPEAN SEARCH REPORT

0031614

Application number
EP 80 20 1181

DOCUMENTS CONSIDERED TO BE RELEVANT			CLASSIFICATION OF THE APPLICATION (Int. Cl.³)
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	G 10 K 11/34 11/02
	DE - A - 2 718 772 (TOKYO SHIBAURA ELECTRIC CO. LTD.) * page 9, paragraph 1 to page 11, paragraph 1; page 13, paragraph 2; figures 1-4 * & GB - A - 1 553 933 --	1,2,5,9	
	DE - A - 2 818 915 (ANVAR) * page 18, paragraph 3 to page 19, paragraph 1; page 29, paragraph 3 to page 30, paragraph 2; figures 2,5-9,12,16-22 * --	1	TECHNICAL FIELDS SEARCHED (Int. Cl.³) G 10 K 11/02 11/32 11/34 G 01 H 3/12 G 01 N 29/00
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	ULTRASONICS, vol. 16, no. 5, September 1978 GUILDFORD (GB) "Industrial News" "Transducers for Control Applications" pages 197-198 * the whole article * --	4	CATEGORY OF CITED DOCUMENTS X: particularly relevant A: technological background O: non-written disclosure P: intermediate document T: theory or principle underlying the invention E: conflicting application D: document cited in the application L: citation for other reasons
E/P	GB - A - 2 033 579 (BABCOCK POWER LTD.) * page 2, lines 62 to 102; ./.	1,3	
X	The present search report has been drawn up for all claims		&: member of the same patent family, corresponding document

Place of search	Date of completion of the search	Examiner
The Hague	20-03-1981	STUBNER

EPO Form 1503.1 06.78

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EUROPEAN SEARCH REPORT

DOCUMENTS CONSIDERED TO BE RELEVANT			CLASSIFICATION OF THE APPLICATION (Int. Cl.3)
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	
	figures 1-3 * --		
A	ULTRASONICS, vol. 14, no. 1, January 1976 GUILDFORD (GB) WHITTINGHAM: "A hand-held electronically switched array for rapid ultrasonic scanning" pages 29-33 * page 29, right-hand column, chapter: "Probe design and construction" to page 30, right-hand column, paragraph 3; figures 1-3 * --	1,2	
A	DE - A - 2 605 776 (GESELLSCHAFT FUR STRAHLEN- UND UMWELT-FORSCHUNG mbH) * page 7, last paragraph; figure 2 * -------		TECHNICAL FIELDS SEARCHED (Int. Cl.3)